ALKYL PUSH FLOW FOR VERTICAL FLOW ROTATING DISK REACTORS

TECHNICAL FIELD OF THE INVENTION

The present invention relates to metal organic chemical vapor phase deposition reactors. More particularly, the present invention relates to rotating disk reactors in which one or more gases are injected onto the surface of a rotating substrate to grow epitaxial layers thereon.

BACKGROUND OF THE INVENTION

Vertical high-speed rotating disk reactors, in which the gas or gases are injected downwardly onto a substrate surface rotating within a reactor, are frequently employed for metal organic chemical vapor deposition (MOCVD). Vertical disk-type CVD reactors, in particular, have been found useful for wide varieties of epitaxial compounds, including various combinations of semiconductor single films and multilayered structures such as lasers and LED'S. In these reactors, one or more injectors spaced above a substrate carrier provide a predetermined gas flow, which upon contact with the substrate, deposits layers of epitaxial material on the surface of the substrate.

For larger wafers, rotating disk reactors employ several injectors spaced above the substrate. The injectors are typically spaced above the wafer in various positions along one or more radial axes of the wafer, relative to the central axis of the substrate carrier. Frequently, the rate of source reactant material injected into the reactor varies from injector to injector to permit the same molar quantity of reactant to reach the surface of the substrate. Hence, some reactant injectors may have different gas velocities than others. This variation in reactant velocity is, in pertinent part, due to the relative placement of the injectors. As the reactor carrier holding the substrate rotates at a predetermined rate, the injectors near the outer edge of the carrier cover a larger region of surface area on the carrier than the injectors closer to the center of the carrier in any given time period. Thus, the outer injectors typically employ a greater gas velocity of reactant than the inner injectors in order to maintain desired uniformity. For example, individual injector gas velocities may differ by a factor of as much as three to four between adjacent injectors.

While this variation in gas velocity helps to ensure a more uniform layer thickness, it may also cause turbulence between the injector flows due to their varying velocities. Also, the risk of side effects such as uneven layer thickness, dissipation of reactant, or premature condensation of reactant may be increased.

DISCLOSURE OF THE INVENTION

One aspect of the invention provides a reactor. A reactor according to this aspect of the invention preferably includes a chamber and a substrate carrier mounted for movement within the chamber, most preferably for rotational movement about an axis. The substrate carrier is adapted to hold one or more substrates, most preferably so that surfaces of the substrates to be treated lie substantially perpendicular to the axis. The reactor according to this aspect of the invention desirably includes a gas stream generator arranged to deliver one or more gas streams within the chamber directed toward the substrate carrier at a substantially uniform velocity.

The gas stream generator most preferably is arranged so that the one or more gas streams include a carrier gas and a reactant gas, and so that different portions of the one or more gas streams contain different concentrations of the reactant gas. Where the substrate carrier is mounted for rotational movement about an axis, the gas stream generator desirably is arranged to supply said one or more gas streams with different concentrations of the reactant gas at different radial distances from the axis. The gas directed towards a portion of the substrate carrier near the axis desirably includes a relatively large concentration of the carrier gas and a relatively small concentration of the reactant gas, whereas the gas directed towards a portion of the substrate carrier desirably includes a high concentration of the reactant gas.

The gas stream generator may include a plurality of gas inlets communicating with the chamber at different distances from the axis, as well as one or more sources of a reactant gas connected to the inlets and one or more sources of a carrier gas connected to at least one of inlets.

A further aspect of the invention includes methods of treating substrates. A method according to this aspect of the invention desirably includes rotating a substrate support about an axis while supporting one or more substrates to be treated on the support so that surfaces of the substrates lie substantially perpendicular to said axis. The method further includes introducing a reactant gas and a carrier gas into the chamber so that said gases flow within said chamber toward the surfaces in one or more streams having substantially uniform velocity at different radial distances from said axis. The one or more gas streams are arranged so that different portions of the substrate surfaces at different radial distances from the axis receive substantially the same amount of said reactant gas per unit time per unit area. Most preferably, the step of introducing the carrier gas and reactant gas includes mixing at least some of the reactant gas with the carrier gas so that gas flowing toward

radially outward portions of the substrate surfaces has a higher concentration of the reactant gas than gas flowing toward radially inward portions of the surfaces, close to the axis.

Preferred reactors and methods according to the foregoing aspects of the invention can provide uniform distribution of the reactant gas over the treatment surface of a substrate carrier, such as over the surface of a rotating disk substrate carrier, while avoiding turbulence caused by differing reactant gas velocities.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1A is a schematic view depicting a reactor according to one embodiment of the present invention.

Fig. 1B is a top plan view of a substrate carrier used in the embodiment of Fig. 1A.

Fig. 2 is a fragmentary sectional elevational view depicting a reactor according to another embodiment of the invention.

Fig. 3 is a fragmentary view along line 3-3 in Fig. 2.

Fig. 4 is a fragmentary bottom plan view of a plate used in a reactor according to a further embodiment of the invention.

Fig. 5A is a fragmentary sectional elevational view depicting a reactor according to yet another embodiment of the invention.

Fig. 5B is a sectional view along line 5B-5B in Fig. 5A.

Figs. 6, 7 and 8 are view similar to Fig. 4 but depicting portions of plates used in reactors according to additional embodiments of the invention.

MODES FOR CARRYING OUT THE INVENTION

An apparatus according to one embodiment of the invention, depicted schematically in Fig. 1, includes a reaction chamber 1 and a substrate carrier 2. The chamber includes a top wall 16 and an exhaust port 11. The substrate carrier 2 is mounted within the chamber 1 for rotation about a central axis 14 and connected to a rotary drive system 12 so that the substrate carrier 2 can be rotated around the axis 14. The substrate carrier 2 defines a treatment surface 18 in the form of a generally planar disc perpendicular to axis 14 and facing toward top wall 16. Only a portion of such surface 18 is depicted in Fig. 1. The reaction chamber 1 is equipped with other conventional elements (not shown) for facilitating the desired epitaxial growth reaction as, for example, a heating system for maintaining the substrate carrier at an elevated temperature, temperature monitoring devices and pressure

monitoring devices. These features of the apparatus may be of the type used in reactors sold under the trademark TURBODISC® by the Emcore Corporation of Somerset, New Jersey.

The reactor has a plurality of gas stream inlets 8a-8d communicating with the interior of the chamber through top wall 16. In the embodiment of Fig. 1, each inlet is in the form of a single port directed downwardly in a direction parallel to central axis 14 towards the treatment surface 18 of the carrier, and the port of each inlet is of the same size. Gas stream inlets 8a-8d are arranged along a common plane which extends radially from central axis 14. The common plane is a plane defined by axis 14 and a radial line 17 extending perpendicular to axis 14. The gas stream inlets 8a-8d are spaced apart from one another, for example, by a uniform spacing distance h in the radial direction. Each inlet 8 is aligned with a different annular zone of treatment surface 18. Thus, outermost or first inlet 8a is aligned with an outermost zone 10a furthest from axis 14; inlet 8b is aligned with the next zone 10b; inlet 8c is aligned with zone 10c, and inlet 8d is aligned with the innermost zone 10d, closest to axis 14. Although the zone borders are indicated by broken lines in Fig. 1 for clarity of illustration, these zones typically are not delineated by visible features of the substrate carrier.

The reactor includes a plurality of reaction gas sources 6a-6d, each such source being adapted to supply a reaction gas at a predetermined mass flow rate. Any device capable of providing the reaction gas at a predetermined rate may be used. In the arrangement illustrated, each reaction gas source 6a-6d is a flow restricting device, and all of the sources are connected to a common supply 4 of the reaction gas as, for example, a tank holding such gas under pressure. The flow restricting device incorporated in each gas sources 6a-6d may include any conventional flow control structure such as a fixed orifice, a manually adjustable valve or an automatically-controlled valve linked to a feedback control system (not shown) or a metering pump. Where the reactant gas is formed by vaporization from the liquid phase, each reactant gas source may include a separate evaporator arranged to control the rate of vaporization, or else each gas source may include a flow restricting device as discussed above, all of these being connected to a common evaporator.

The reactant gas may be any gas, vapor, or material desired to be injected into the reactor to participate in the deposition of a substrate within the reactor. More particularly, the reactant gas may be any gas which is suitable for treating the substrate surface. For example, where the desired treatment is growth of a semiconductor layer such as epitaxial growth, the reactant gas includes one or more constituents of the semiconductor to be grown. For example, the reactant gas may include

one or more metal alkyls for deposition of a compound semiconductor. The reactant gas may be a mixture of plural chemical species, and may include inert, non-reactive components. Where the desired reaction includes etching of a substrate surface, the reactant gas may include a constituent reactive with the material of the substrate surface.

The types of material systems to which the present invention can be applied can include, for example, epitaxial growth of Group III-V semiconductors such as GaAs, GaP, $GaAs_{1-x}P_x$, $Ga_{1-y}Al_yAs$, $Ga_{1-y}In_yAs$, AlAs, InAs, InP, InGaP, InSb, GaN, InGaN, and the like. However, the invention can also be applied to other systems. These include Group II-VI compounds, such as ZnSe, CdTe, HgCdTe, CdZnTe, CdSeTe, and the like; Group IV--IV compounds, such as SiC, diamond, and SiGe; as well as oxides, such as YBCO, BaTiO, MgO_2, ZrO, SiO_2, ZnO and ZnSiO; and metals, such as Al, Cu and W. Furthermore, the resultant materials will have a wide range of electronic and opto-electronic applications, including high brightness light emitting diodes (LED's), lasers, solar cells, photocathodes, HEMT's and MESFET's.

Carrier gas sources 7a-7d are also provided. The carrier gas sources 7a-7d may be similar in structure to the reaction gas sources, and may be connected to a common supply5 of a carrier gas. Each gas stream inlet 8a-8d is connected to one reaction gas source 6a-6d and to one carrier gas source 7a-7d. For example, inlet 8a is connected to reaction gas source 6a and carrier gas source 7a, whereas inlet 8d is connected to reaction gas source 6d and carrier gas source 7d.

The carrier gas may be any carrier desired which does not participate in the deposition reaction in the chamber given the reactant gasses to be applied to the substrate, such as an inert gas or a non-participating gas in the reaction, or, alternatively the carrier gas may be, for example, itself a reactant gas which serves as a non rate limiting participant in a reaction and thus may be provided in any desired quantity so long as such quantity is in excess of a rate limiting quantity in the reactor at the desired temperature, pressure and conditions of reaction.

In a method according to one embodiment of the invention, substrates 3 in the form of flat, thin discs are disposed on the treatment surface 18 of the substrate carrier 2 so that the substrates 3 overlay the treatment surface 18 and so that the surfaces of the substrates 3 to be treated face upwardly, toward top wall 16. Desirably, the exposed surfaces of the substrate 3 are coplanar or nearly coplanar with the surrounding portions of the treatment surface. For example, a substrate 3 in the form of a relatively thin wafer placed on a treatment surface 18 will have an exposed, upwardly

facing surface elevated above the surrounding portions of the treatment surface 18 by only the thickness of the wafer 3. The treatment surface 18 of the substrate carrier 2 may include pockets or depressions having a depth approximately equal to the thickness of the wafer (not shown).

When the substrate carrier 2 and substrates 3 are at the desired temperature for the reaction, and the interior of the chamber 1 is at the desired subatmospheric pressure for the particular reaction to be accomplished, the reaction gas sources 6a-6d and carrier gas sources 7a-d are actuated to supply gasses to inlets 8a-8d. The reactant gas 4 and carrier gas 5 supplied to each inlet mix to form a combined gas stream 9a-9d issuing from each inlet 8a-8d. The gas streams 9a-9d issuing from the inlets flow downwardly into the chamber, in the axial direction parallel to axis 14, and impinge on the treatment surface and on the exposed surfaces of the substrates 3. The gas streams 9a9d from different inlets 8a-8d impinge on different zones 10a-10d of the treatment surface 18. For example, stream 9a issuing from inlet 8a impinges predominantly on innermost zone 10a, whereas streams 9b, 9c and 9d impinge predominantly on zones 10b, 10c and 10d, respectively. Thus, although the streams 9a-9d merge with one another to form a substantially continuous, radially elongated stream or curtain of gas flowing towards the substrate carrier, the individual streams 9a-9d of from the various inlets 8a-8d pass to different zones 10a-10d of the treatment surface 18. Stated another way, the gas impinging on innermost zone 10d of the treatment surface 18 is composed principally of gas in stream 9d from inlet 8d, whereas the gas impinging on zone 10b is composed principally of gas in stream 9b from inlet 8b, and so on. As the substrate carrier2 rotates at a predetermined rotation rate α, different portions of the carrier 2 at different circumferential positions around axis 14 are brought into alignment with the gas streams 9a-9d, so that exposure of the treatment surface 18 to the gas streams 9a-9d is the same at all circumferential positions.

To provide equal reaction rates on the various regions of the exposed substrate 3 surfaces, all regions 10a-10d of the treatment surface 18 should be provided with equal amounts of reactant gas 4 per unit area of treatment surface per unit time. However, the zones 10a-10d supplied by the various gas outlets are of unequal area. For example, zone 10a, adjacent the periphery of the treatment surface, has a larger surface area than zone 10d, adjacent the axis. Accordingly, the reactant gas flow rates provided by sources 6a-6d are selected to provide different flow rates of reactant gas in the streams 9a-9d issuing from the various inlets 8a-8d. Unless otherwise indicated, the flow rates referred to in this discussion are molar flow rates. The molar flow rate represents the number of

molecules of gas (or atoms in a monatomic gas) per unit time. Source 6a is arranged to supply reactant gas at a relatively large flow rate to inlet 8a for stream 9a, whereas source 6d is set to supply reactant gas at a relatively small flow rate to inlet 8d for stream 9d. Sources 6b and 6c supply the reactant gas at intermediate flow rates. Stated another way, the reactant gas flow rate increases in direct relation to the distance between the central axis 14 of rotation for the substrate carrier 2 of the reactor 1 and the gas inlet 8a-8d to be supplied with reactant gas.

Carrier gas sources 7a-7d are set to supply the carrier gas 5 at different flow rates to the various inlets 8a-8d. The flow rates of the carrier gas are selected so that the velocities of the various streams 9a-9d will be equal to one another. For inlets of the same configuration — which provide streams of equal cross-sectional area — the volumetric flow rate of the streams 9a-9d issuing from each inlet 8a-8d should be equal.

As a first approximation, assuming that the gases are near ideal gases, the volumetric flow rate of the gas in each stream is directly proportional to the total molar flow rate in the stream, *i.e.*, to the sum of the reactant gas molar flow rate and the carrier gas molar flow rate. Thus, to provide streams having equal total molar flow rates and hence equal velocity, the carrier gas molar flow rate supplied by source 7d to inlet 8d must be greater than the carrier gas molar flow rate supplied by source 7a to inlet 8a. The greater carrier gas flow rate supplied to inlet 8d and incorporated in stream 9d compensates for the smaller reactant gas flow rate from reactant gas source 6d relative to that provided by reactant gas source 6a to inlet 8a.

Stated another way, the various streams have the same total volumetric flow rate but different concentrations of reactant gas. Stream 9a impinging on the largest zone 10a has the highest reactant gas flow rate, and the lowest carrier gas flow rate, whereas stream 9d impinging on the smallest zone 10d has the lowest reactant gas concentration, and hence the highest carrier gas flow rate.

This arrangement is indicated graphically by bars 13a-13d in Fig. 1. The overall length C of bar 13d represents the total molar flow rate or volumetric flow rate of stream 9d issuing from inlet 8d. The length of the darkened portion of this bar represents the reactant gas molar flow rate v_a in the stream, whereas the white portion of the bar represents the carrier gas molar flow rate i_a in the same stream 9d. Bars 13a, 13b and 13c similarly represent the composition and flow rate of streams 9a, 9b and 9c respectively. The overall lengths C of all bars 13 are equal, but bars 13a, 13b and 13c represent the progressively greater reactant gas molar flow rates v_c, v_b and v_a and progressively lower

carrier gas molar flow rates i_c, i_b, i_a in streams 9c, 9b and 9a. By supplying the various streams 9a-9d at different concentrations of reactant gas but at the same total stream velocity, the system avoids turbulence and other flow irregularities which would be created by streams of different velocities, and yet supplies substantially equal molar flow rates of reactant gas per unit area to the various zones of the of the treatment surface.

Thus, the exposed surfaces of the wafer 3 at all portions of the treatment surface 18 receive substantially the same amount of reactant gas per unit time per unit area. The reaction thus proceeds at a substantially uniform rate over all of the exposed wafer surfaces 3. For example, where the reaction involves deposition of a layer such as epitaxial growth, the deposited layer grows at a substantially uniform rate on the various exposed surfaces.

The system can be varied to deliver unequal amounts of reactant gas per unit surface area per unit time. For example, the gas flow pattern within the reactor may include some flow in the radially outward direction, away from axis 14 at or near the treatment surface. Such flow may tend to carry some unreacted reactant gas from the innermost zone 10d toward the outermost zone 10a. To compensate for this effect, the gas sources can be adjusted to deliver slightly more reactant gas to the innermost zone, as by increasing the reactant gas concentration in innermost stream 9d above that which would be required to achieve exactly equal reactant gas flow per unit time. In this case, the reactant gas flow and reactant gas concentration will not be exactly proportional to radial distance from axis 14. However, the system still uses multiple gas streams of differing concentration but the same velocity to provide a downwardly or axially flowing gas curtain having substantially uniform velocity but unequal reactant gas concentration at different radial locations.

In another variant, the reactant gas concentration in the gas stream from the outermost inlet 8a may be 100%, so that the downwardly-flowing gas impinging on the outermost zone consists entirely of the reactant gas, with no carrier gas. In this instance, carrier gas source 7a associated with inlet 8a may be omitted. Also, the principles discussed above can be applied with more or fewer gas inlets directed onto more or fewer zones.

In apparatus according to a further embodiment of the invention, seen in Fig. 2 and 3, the gas stream inlets are not disposed in a radial plane on one side of the axis of rotation as discussed above with reference to Fig. 1. Instead, in the embodiment of Figs. 2 and 3, the outermost gas inlet 108a is disposed on one side of the axis of rotation 114 of substrate carrier 102, and at a large radial distance

from the axis, whereas the next gas inlet 108b lies on the opposite side of axis 114 but at a lesser radial distance from the axis. Inlets 108c and 108d, at lesser radial distances from axis 114, also lie on opposite sides of the axis along a common diameter 219 (Fig. 3). Here again, the different gas streams 109a-109d impinge on different zones of treatment surface 118 having different areas. The carrier gas flows from carrier gas sources 107a-107d and the reactant gas flows from reactant gas sources 106a-106d are selected in the same manner as described above, so as to provide gas streams 109a-109d with different reactant gas concentrations and flow rates, but with the same velocity. In a further variant, the gas inlets may be provided as two complete sets, one on each side of the central axis, each such set including a full complement of gas inlets adapted to direct gas onto all of the zones of the treatment surface. More than two sets of gas inlets may be provided as, for example, four sets disposed on two diameters. In a further variant (Fig. 4) the various gas inlets 36a-36g may be distributed along different radii 17a-17g, and at different radial distances from the central axis 114.

In the apparatus discussed above, each gas stream is formed by mixing carrier gas and reactant gas prior to introducing the mixed gases into the reaction chamber. However, this is not essential. In the apparatus of Figs. 5A and 5B, the innermost gas inlet 208d includes two separate ports opening through reactor top wall 216: a reactant gas port 230d and a carrier gas port 232d. The reactant gas port 230d is connected to a reactant gas source 206d, whereas the carrier gas port 232d is connected to a carrier gas source 207d. Ports 230d and 232d are disposed adjacent to one another, so that the carrier gas introduced through port 232d merges with the reactant gas introduced through port 230d just after the gases enter the interior of reaction chamber 201, and form a combined gas stream passing downwardly onto the associated zone of treatment surface 218. Each of the other inlets 208a-208c is constituted by a similar pair of ports, and operates in the same manner.

The apparatus of Figs. 5A and 5B also includes a porous plate 215 mounted within reaction chamber 210, between top wall 216 and the treatment surface. As discussed in greater detail in United States Patent 6,197,121, the disclosure of which is incorporated by reference here, such a porous plate can include, for example, a wire mesh screen supported by a set of coolant conduits. The porous plate has an upstream or inlet side facing toward the top wall 216, and has a downstream side facing toward substrate carrier 202 (toward the bottom of the drawing in Fig. 5A). The porous plate 215 is spaced from the top wall. A set of barrier walls 250 extend between the top wall 216 and

the porous plate 215 in the vicinity of inlets 208a-208d. The barrier walls 250 subdivide the space upstream of the porous plate into spaces 254a-254d. Each gas inlet 208a-208d opens into one such space. Additional walls 256 separate spaces 254a-254d from other spaces 258 (Fig. 5B) disposed upstream of the porous plate.

In operation, the carrier gas and reactin gas provided through each inlet mix within the space 254 associated with that inlet, and pass through a region of the porous plate aligned with such space. For example, the combined gasses provided by inlet 208d, including reactant gas from port 230d and carrier gas from port 232d, passes downstream through a region of the porous plate 215, and passes from the downstream side of the injection plate to the treatment surface as a stream 209d, so that this stream impinges principally on the innermost region 210d of the treatment surface 218. In the same manner, the gases from inlets 208c, 208b and 208d mix in spaces 254c, 254b and 254a, respectively, to form streams 209c, 209b and 209a, which impinge on other regions of the treatment surface. Although the individual streams are depicted separately in Fig. 5A for clarity of illustration, in actuality the streams spread radially and merge with one another enroute from the porous plate 215 to the treatment surface. Here again, the flow rates of the carrier gas and reaction gas supplied by each of the gas sources are selected so that the total flow rate in each stream 209, and hence the velocity of each stream, is substantially equal, but the concentration of reactant gas in the various streams is unequal. In this arrangement as well, additional sets of inlets 208' for the carrier gas and reaction gas may be provided at other locations spaced circumferentially around central axis 214. Each such set is arranged in the same manner as inlets 208a-208d. Also, other gases used in the growth process can be introduced through additional inlets (not shown) connected to additional spaces 258. Such other gases can be introduced at the same time as the carrier gas and reactant gas, or at other times, during other stages of the process.

A similar porous plate may be used with inlets such as those discussed above with reference to Figs. 1A and 2.

In apparatus according to a further embodiment (Fig. 6), the ports constituting the inlets act to control the amounts of gases in each gas steam. In this embodiment, the outermost gas inlet 308a includes a reaction gas port 330a and a carrier gas port 332a, whereas each of the other gas inlets 308b, 308c and 308d includes a similar pair of ports. Here again, the ports constituting each gas inlet are disposed adjacent to one another. The ports are arranged along a common radial line

317. All of the reaction gas ports 330a, 330b, 330c and 330d are connected to a common conduit 306 which in turn is connected to a supply of reactant gas, so that all of the reactin gas ports are supplied with the reaction gas at substantially the same pressure. Likewise, all of the carrier gas ports 332a, 332b, 332c and 332d are connected to a common conduit 307, which in turn is connected to a supply of the carrier gas, so that all of the carrier gas ports are supplied with the carrier gas at substantially the same pressure. The sizes of the ports, and hence the flow resistances of the ports, differ. Reactant gas port 330a of the outermost gas inlet 308a is relatively large, and has relatively low flow resistance, whereas carrier gas port 332a of the outermost gas inlet is relatively small, and hence has high flow resistance. Accordingly, the gas stream issuing from these ports and hence from gas inlet 308a will incorporate a large proportion of reactant gas and a small proportion of carrier gas. Conversely, reactant gas port 330d of the innermost gas inlet 308d is relatively small, and has high flow resistance, whereas the carrier gas port 332d of the same inlet is relatively large, and has high flow resistance. The gas stream issuing from inlet 308d will have a relatively large proportion of carrier gas. As will be appreciated with reference to Fig. 6, the sizes of the reactant gas ports 330 increase progressively in the radially outward direction, away from axis 314, *i.e.*, in the direction from the smallest zone of the treatment surface to the largest zone, so that the flow resistance of the reactant gas ports decreases progressively in this direction. Conversely, the flow resistance of the carrier gas ports increases progressively in the same direction. The apparatus thus will provide gas streams having substantially the same total flow rate (carrier gas plus reactant gas) but differing concentrations of reactant gas, impinging on the differing zones of the treatment surface. Plural sets of ports as described above can be provided along numerous radial lines, so as to provide a plurality of such streams around the circumference of the chamber.

In a further variant (Fig. 7) the separate ports and inlets of are replaced by a carrier gas passage 432 and reactant gas passage 430 extending through top plate 416. The downstream ends of these passages (the ends of the passages opening into the reaction chamber) are visible in Fig. 7. The passages are disposed side-by-side. Carrier gas passage 432 is connected to carrier gas conduit 407, whereas reactant gas passage 430 is connected to a reactant gas conduit 406. Conduits 407 and 406 are connected to supplies of carrier gas and reactant gas, respectively. The carrier gas passage 432 has a width w432 which decreases progressively in the radially outward direction away from axis 414. Thus, the resistance of the carrier gas passage to flow of the carrier gas in the downstream

direction of the passage (the direction out of the plane of the drawing in Fig. 7) increases progressively in the radially outward direction. The reactant gas passage has a width w430 which increases progressively in the radially outward direction, so that the resistance of the reactant gas passage to downstream flow of reactant gas decreases progressively in the radially outward direction. In operation, a relatively large amount of reactant gas passes through the radially outer portion of the reactant gas passage 430 whereas a relatively small amount of carrier gas passes through the radially outer portion of carrier gas passage 432. Conversely, a small amount of reactant gas and a large amount of carrier gas pass through the radially inner portions of the passages. The carrier and reactant gases merge to form a gas stream passing downstream (in the direction out of the plane of the drawing in Fig. 7), such gas stream having a substantially constant total flow rate per unit radial distance and substantially constant velocity at all radial locations but having progressively increasing reactant gas concentration in the radially outward direction.

A reactor according to a further embodiment of the invention, shown in Fig. 8, has a reactant gas passage 530 and carrier gas passage 532 similar to the passages discussed above with reference to Fig. 7. In the reactor of Fig. 8, however, the passages have constant width over their radial extent. Reactant gas passage 530 is filled with a mesh or other porous structure 531 having progressively increasing porosity in the radially outward direction, away from axis 514. Accordingly, the resistance of passage 530 to downstream flow of reactant gas decreases in the radially outward direction. The carrier gas passage 532 is filled with a porous structure 533 having progressively decreasing porosity, and hence progressively increasing flow resistance, in the radially outward direction. The net effect is the same as discussed with reference to Fig. 7. Other features of the passageways can be varied to achieve similar variations in flow resistance along the radial extent of the passageways. For example, the passageways can include baffles or partial obstructions disposed at various radial locations. In yet another variant, each passage can have different lengths, in the downstream direction of the passage, at its inner and outer edges. For example, where a passage extends through a plate, the thickness of the plate can vary in the radial direction so as to vary the length of the passage, and hence the flow resistance of the passage, in the radial direction.

Although the invention herein has been described with reference to particular embodiments, it is to be understood that these embodiments are merely illustrative of the principles and applications of the present invention. It is therefore to be understood that numerous modifications may be made

to the illustrative embodiments and that other arrangements may be devised without departing from the spirit and scope of the present invention as defined by the appended claims.

INDUSTRIAL APPLICABILITY

The present invention is applicable to the electronics manufacturing industry and where it is desired to manufacture electronics components in large number through the epitaxial growth of materials thereon. The present invention is applicable to, for example, vertical disk reactors for the epitaxial growth of materials on silicon wafers for electronics components.